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(54) **LIQUID CRYSTAL LENS DEVICE AND IMAGE DISPLAY DEVICE**

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G02B 27/26 (2006.01)

(52) **U.S. Cl.**
CPC ***G02B 27/26*** (2013.01); ***G02F 1/134336*** (2013.01); ***G02F 1/134363*** (2013.01); *G02F 2001/134345* (2013.01); *G02F 2001/134381* (2013.01)

(58) **Field of Classification Search**
CPC G02F 1/134363; G02F 2001/134381; G02B 27/2214; G02B 27/02
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2007/0195410 A1	8/2007	Yun et al.		
2010/0238276 A1	9/2010	Takagi et al.		
2012/0069255 A1	3/2012	Takagi et al.		
2012/0162550 A1*	6/2012	Jeong	H04N 13/0404	349/15

FOREIGN PATENT DOCUMENTS

JP	2007-226231	9/2007
JP	2010-224191	10/2010
JP	2013-218113	10/2013
WO	WO 2011/036736	3/2011

* cited by examiner

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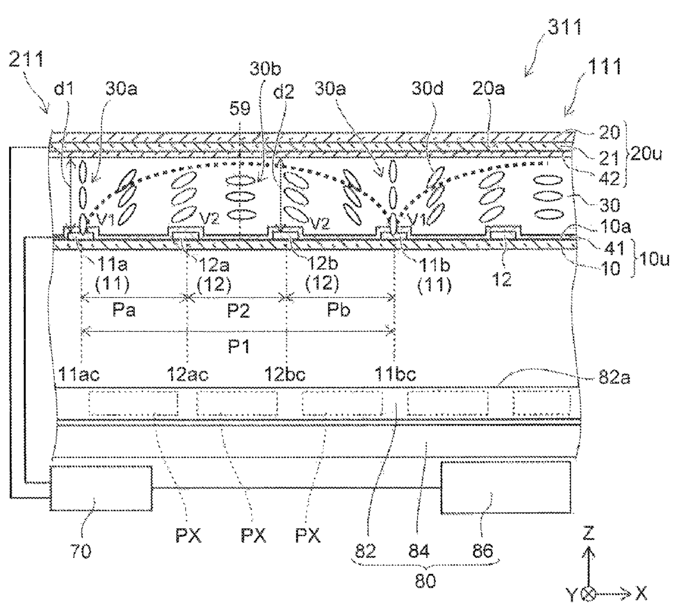
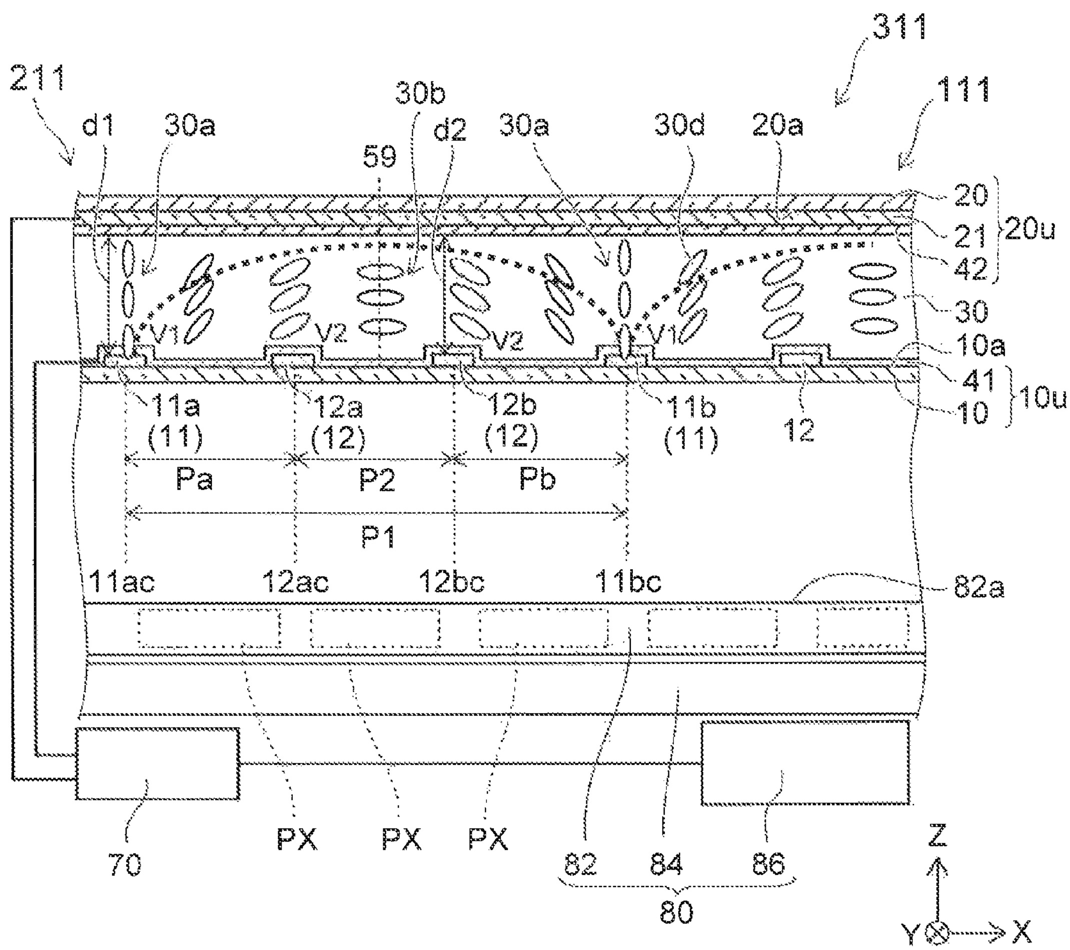
(57) **ABSTRACT**

A liquid crystal lens device includes first electrodes, first and second sub electrodes, an opposite electrode, and a liquid crystal layer. The first electrodes extend in a first direction and are arranged in a second direction crossing the first direction. The first sub electrode is provided between a center in the second direction of two nearest ones of the first electrodes and one of the two nearest first electrodes. The second sub electrode is provided between the center and the other of the two nearest first electrodes. The opposite electrode is opposed to each of the first electrodes, the first sub electrode, and the second sub electrode. The liquid crystal layer is provided between the first electrodes and the opposite electrode, between the first sub electrode and the opposite electrode, and between the second sub electrode and the opposite electrode.

20 Claims, 5 Drawing Sheets





311
211
111
d1
30a
30b
d2
59
30a
30d
20a
20
21
20u
42
30
V1
V2
V2
V1
10a
41
10u
10
11a
(11)
12a
(12)
12b
(12)
11b
(11)
12
Pa
P2
Pb
P1
11ac
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PX
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86
80
Z
Y
X

FIG. 1

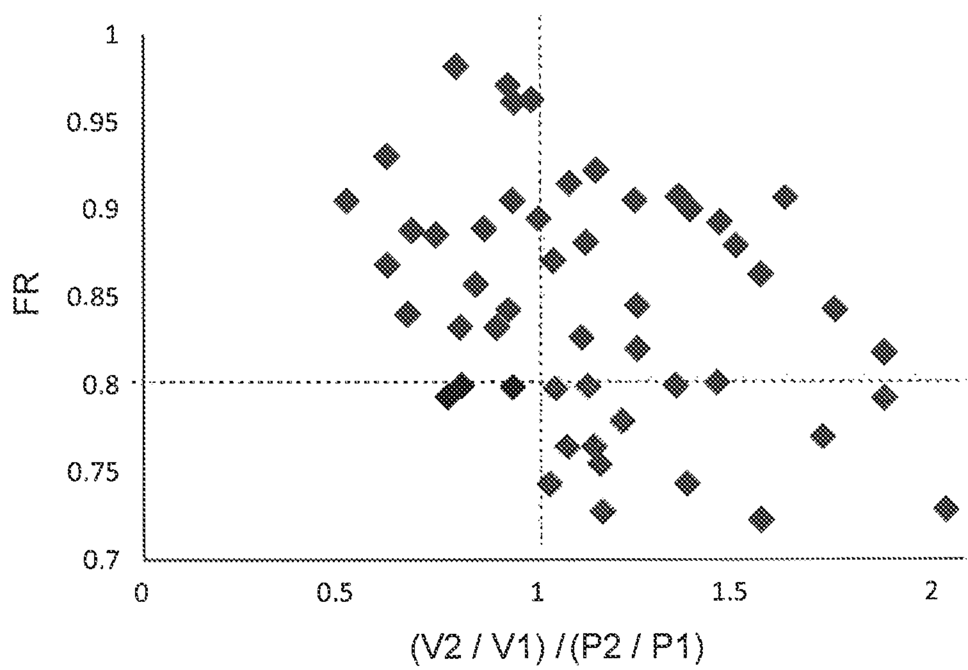


FIG. 2

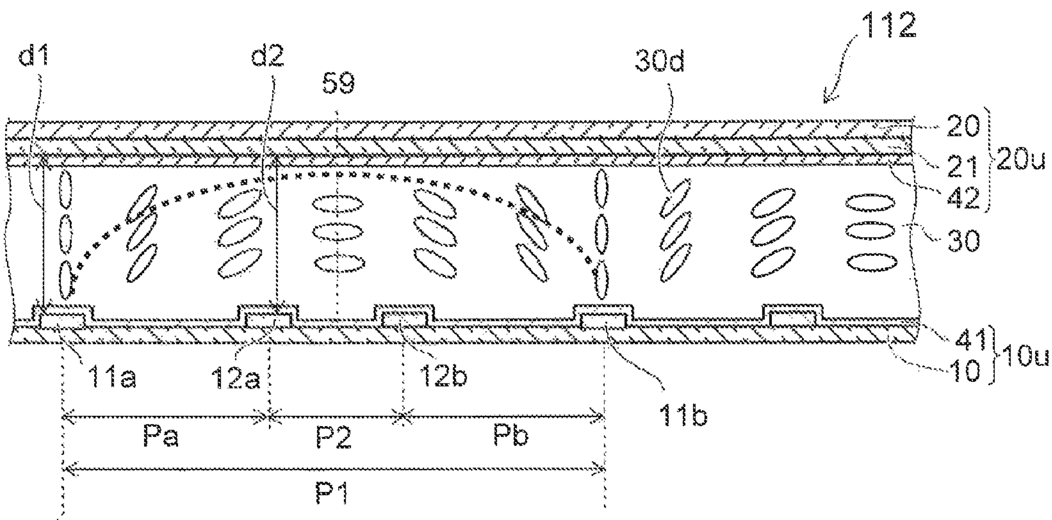

112
d1
d2
59
30d
20
21
20u
42
30
41
10u
10
11a
12a
12b
11b
Pa
P2
Pb
P1

FIG. 3A

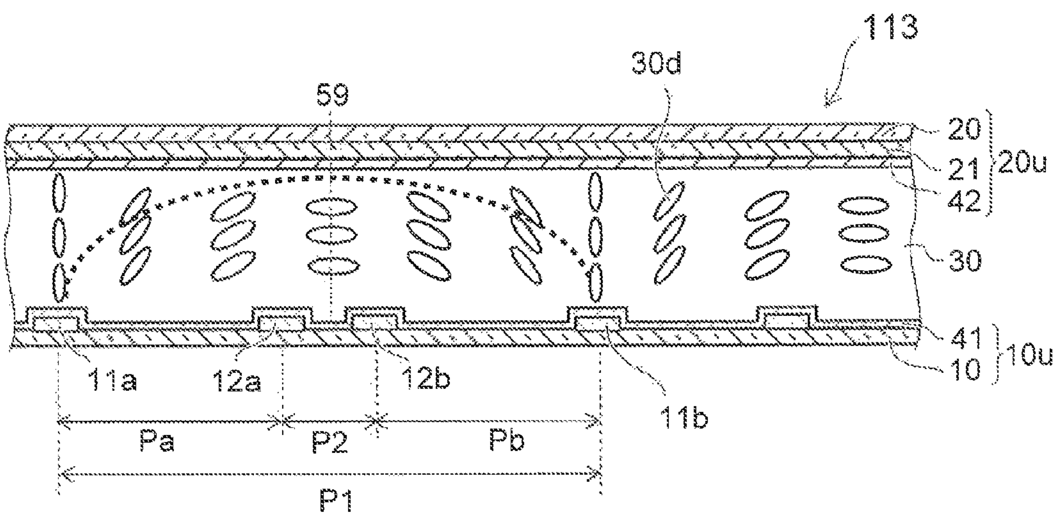
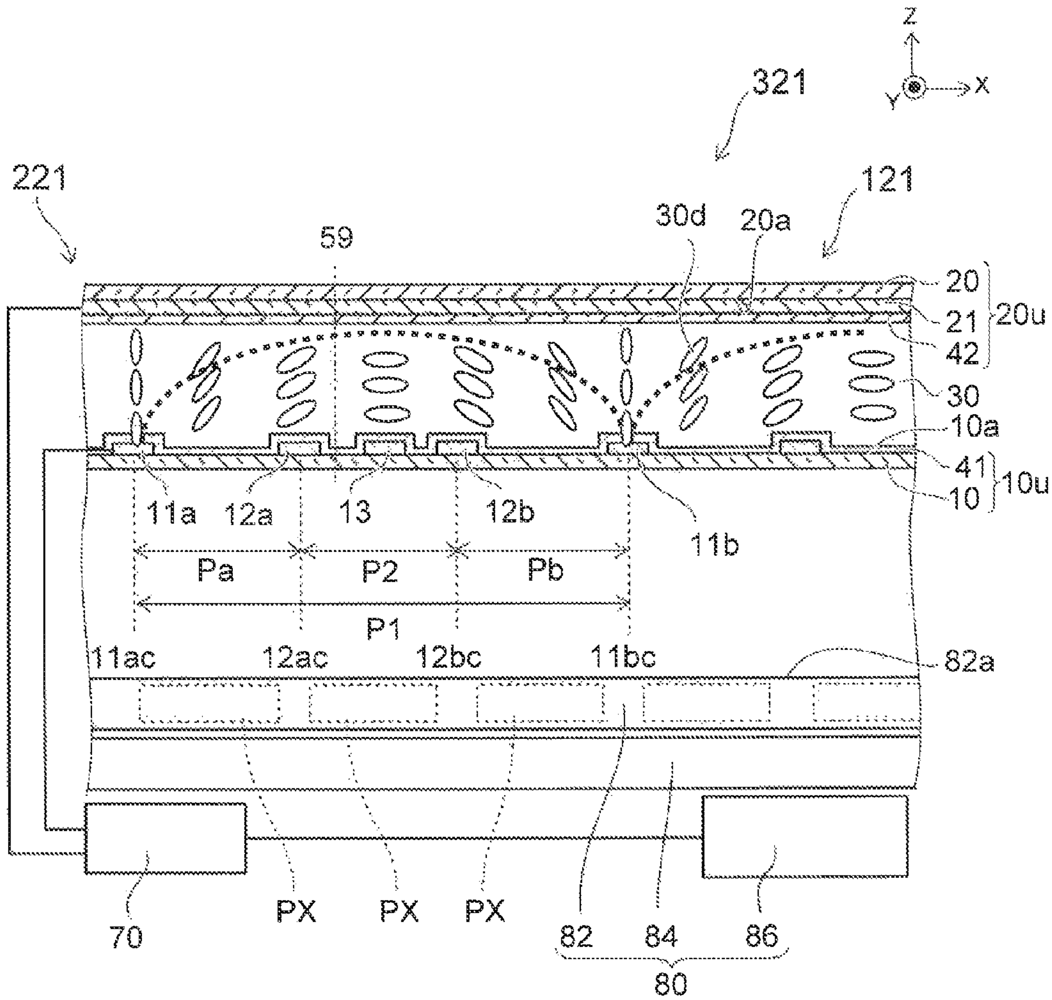

113
30d
59
20
21
20u
42
30
41
10u
10
11a
12a
12b
11b
Pa
P2
Pb
P1

FIG. 3B



321
Z
Y
X
221
121
59
30d
20a
20
21
20u
42
30
10a
41
10u
10
11a
12a
13
12b
11b
Pa
P2
Pb
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12bc
11bc
82a
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PX
82
84
86
80

FIG. 4

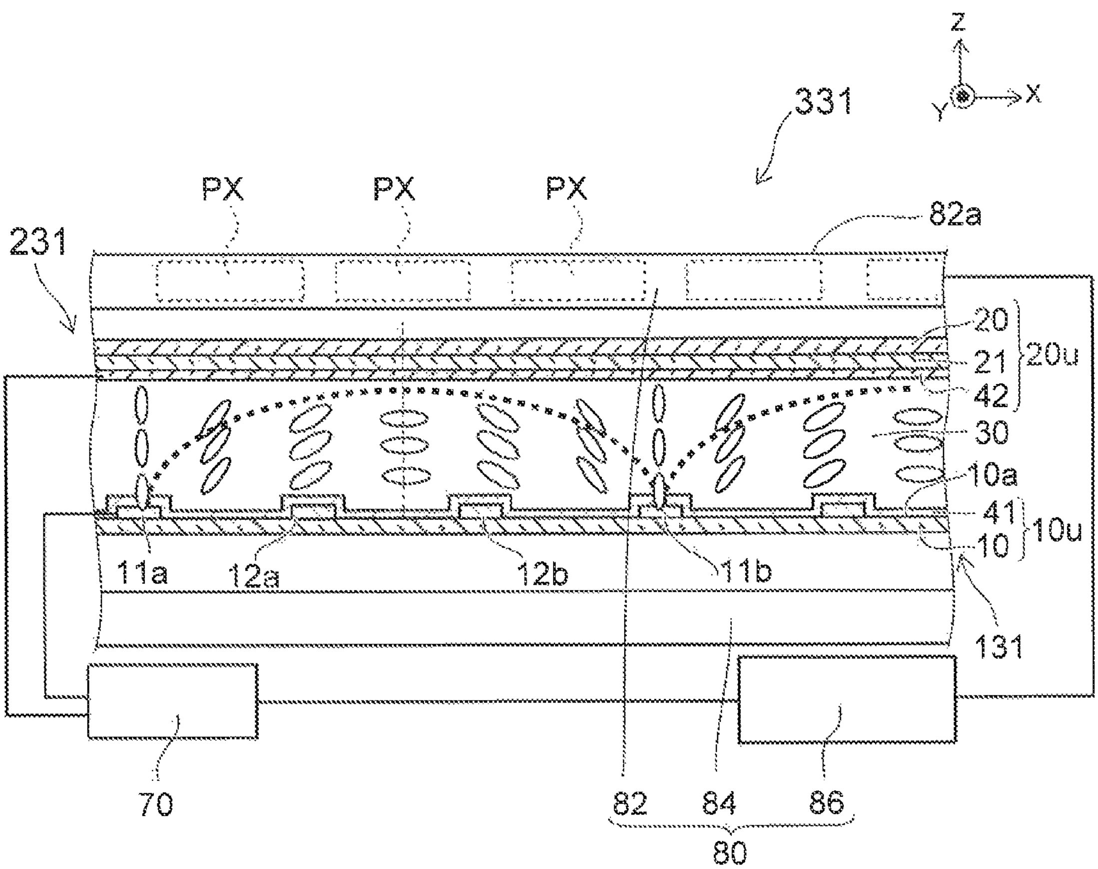
Z
Y
X
331
PX
PX
PX
82a
231
20
21
20u
42
30
10a
41
10u
10
11a
12a
12b
11b
131
70
82
84
86
80

FIG. 5

LIQUID CRYSTAL LENS DEVICE AND IMAGE DISPLAY DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2014-141752, filed on Jul. 9, 2014; the entire contents of which are incorporated herein by reference.

FIELD

Embodiments described herein relate generally to a liquid crystal lens device and an image display device.

BACKGROUND

There is known a liquid crystal lens device utilizing birefringence of liquid crystal molecules to change the distribution of refractive index in response to voltage application. There is known an image display device including the liquid crystal lens device combined with an image display unit. In this image display device, the distribution of refractive index of the liquid crystal optical element is changed to switch between two states. In the first state, the image displayed on the image display unit is made directly incident on the observer's eye. In the second state, the image displayed on the image display unit is made incident on the observer's eye as a plurality of parallax images. This realizes a two-dimensional image display operation and a three-dimensional image display operation. High display quality is desired in such an image display device. A high quality lens function is desired in the liquid crystal lens device.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a sectional view schematically showing an image display device according to a first embodiment;

FIG. **2** is a graph schematically showing an example of the characteristics of the liquid crystal lens device according to the first embodiment;

FIGS. **3**A and **3**B are sectional views schematically showing part of an alternative image display device according to the first embodiment;

FIG. **4** is a sectional view schematically showing an image display device according to a second embodiment; and

FIG. **5** is a sectional view schematically showing an image display device according to a third embodiment.

DETAILED DESCRIPTION

According to one embodiment, a liquid crystal lens device includes a plurality of first electrodes, a first sub electrode, a second sub electrode, an opposite electrode, and a liquid crystal layer. The first electrodes extend in a first direction and are arranged in a second direction crossing the first direction. The first sub electrode is provided between a center in the second direction of two nearest ones of the first electrodes and one of the two nearest first electrodes. The second sub electrode is provided between the center and the other of the two nearest first electrodes. The opposite electrode is opposed to each of the first electrodes, the first sub electrode, and the second sub electrode. The liquid crystal layer is provided between the first electrodes and the opposite electrode, between the first sub electrode and the opposite electrode, and between the second sub electrode and the opposite electrode. A distance between the one of the two nearest first electrodes and the first sub electrode and a distance between the other of the two nearest first electrodes and the second sub electrode are longer than a distance between each of the first electrodes and the opposite electrode. V**2**/V**1** is less than or equal to P**2**/P**1**. V**1** is an absolute value of a potential difference between each of the first electrodes and the opposite electrode. V**2** is an absolute value of a potential difference between the first sub electrode and the opposite electrode and between the second sub electrode and the opposite electrode. P**1** is a distance between the two nearest first electrodes. P**2** is a distance between the first sub electrode and the second sub electrode.

According to another embodiment, an image display device includes a liquid crystal lens device and an image display unit. The liquid crystal lens device includes a plurality of first electrodes, a first sub electrode, a second sub electrode, an opposite electrode, and a liquid crystal layer. The first electrodes extend in a first direction and are arranged in a second direction crossing the first direction. The first sub electrode is provided between a center in the second direction of two nearest ones of the first electrodes and one of the two nearest first electrodes. The second sub electrode is provided between the center and the other of the two nearest first electrodes. The opposite electrode is opposed to each of the first electrodes, the first sub electrode, and the second sub electrode. The liquid crystal layer is provided between the first electrodes and the opposite electrode, between the first sub electrode and the opposite electrode, and between the second sub electrode and the opposite electrode. The image display unit is stacked with the liquid crystal lens device in a third direction crossing the first direction and the second direction and includes a display unit configured to output a light including image information. A distance between the one of the two nearest first electrodes and the first sub electrode and a distance between the other of the two nearest first electrodes and the second sub electrode are longer than a distance between each of the first electrodes and the opposite electrode. V**2**/V**1** is less than or equal to P**2**/P**1**. V**1** is an absolute value of a potential difference between each of the first electrodes and the opposite electrode. V**2** is an absolute value of a potential difference between the first sub electrode and the opposite electrode and between the second sub electrode and the opposite electrode. P**1** is a distance between the two nearest first electrodes. P**2** is a distance between the first sub electrode and the second sub electrode.

Various embodiments will be described hereinafter with reference to the accompanying drawings.

The drawings are schematic or conceptual. The relationship between the thickness and the width of each portion, and the size ratio between the portions, for instance, are not necessarily identical to those in reality. Furthermore, the same portion may be shown with different dimensions or ratios depending on the figures.

In this specification and the drawings, components similar to those described previously with reference to earlier figures are labeled with like reference numerals, and the detailed description thereof is omitted appropriately.

First Embodiment

FIG. **1** is a sectional view schematically showing an image display device according to a first embodiment.

As shown in FIG. **1**, the image display device **311** according to this embodiment includes a liquid crystal lens device **211** and an image display unit **80**. The image display unit **80** displays an image. The image display unit **80** can be an arbitrary display device. For instance, the image display unit **80** can be e.g. a liquid crystal display device, an organic EL display device, or a plasma display.

The liquid crystal lens device **211** includes a liquid crystal optical element **111** and a driver **70**. For instance, the liquid crystal optical element **111** is provided on the image display unit **80**. The liquid crystal optical element **111** functions as e.g. a liquid crystal GRIN lens (gradient index lens). The distribution of refractive index of the liquid crystal optical element **111** is variable. One state of the distribution of refractive index corresponds to a first state in which the image displayed on the image display unit **80** is made directly incident on the observer's eye. Another state of the refractive index distribution corresponds to a second state in which the image displayed on the image display unit **80** is made incident on the observer's eye as a plurality of parallax images.

In the image display device **311**, a two-dimensional image display (hereinafter referred to as 2D display) and a three-dimensional image display (hereinafter referred to as 3D display) can be selectively switched by changing the distribution of refractive index of the liquid crystal optical element **111**. The 3D display enables stereovision to the naked eye.

The driver **70** is electrically connected to the liquid crystal optical element **111**. The driver **70** performs e.g. switching between the first state and the second state of the liquid crystal optical element **111**. The driver **70** switches the liquid crystal optical element **111** to the first state when performing 2D display. The driver **70** switches the liquid crystal optical element **111** to the second state when performing 3D display.

The image display unit **80** is inputted with an image signal (video signal) by e.g. a recording medium or external input. The image display unit **80** displays an image corresponding to the inputted image signal. The image display unit **80** displays an image for 2D display when performing 2D display. The image display unit **80** displays an image for 3D display when performing 3D display.

The liquid crystal optical element **111** includes a first substrate unit **10***u*, a second substrate unit **20***u*, and a liquid crystal layer **30**. The first substrate unit **10***u* includes a first substrate **10**, a plurality of first electrodes **11**, and a plurality of second electrodes **12**. The first substrate **10** has a first major surface **10***a*. The plurality of first electrodes **11** are provided on the first major surface **10***a*. Each of the plurality of first electrodes **11** extends in a first direction. The plurality of first electrodes **11** are arranged in a second direction crossing the first direction. FIG. **1** shows two of the plurality of first electrodes **11**. The number of the plurality of first electrodes **11** is arbitrary.

The first direction is referred to as Y-axis direction. The direction parallel to the first major surface **10***a* and perpendicular to the Y-axis direction is referred to as X-axis direction. The direction perpendicular to the X-axis direction and the Y-axis direction is referred to as Z-axis direction. The plurality of first electrodes **11** are arranged in e.g. the X-axis direction. In this example, the second direction is the X-axis direction. The second direction is not limited to the X-axis direction, but may be an arbitrary direction crossing the first direction.

Consider two nearest first electrodes **11** of the plurality of first electrodes **11**. One electrode of the two nearest first electrodes **11** is referred to as first main electrode **11***a*. The other electrode of the two nearest first electrodes **11** is referred to as second main electrode **11***b*.

A central axis **59** exists between the two nearest first electrodes **11** (first main electrode **11***a* and second main electrode **11***b*). As projected on the X-Y plane (the plane parallel to the first major surface **10***a*), the central axis **59** passes through the midpoint of the line segment connecting the center **11***ac* in the X-axis direction of the first main electrode **11***a* and the center **11***bc* in the X-axis direction of the second main electrode **11***b*, and is parallel to the Y-axis direction.

The plurality of second electrodes **12** are respectively provided between the plurality of first electrodes **11** on the first substrate **10**. The plurality of second electrodes **12** extend in the Y-axis direction. The plurality of second electrodes **12** are respectively spaced from the plurality of first electrodes **11** in the X-axis direction.

The plurality of second electrodes **12** include a first sub electrode **12***a* and a second sub electrode **12***b*. The first sub electrode **12***a* is placed between the center (central axis **59**) in the X-axis direction of the two nearest first electrodes **11** and the first main electrode **11***a*. The second sub electrode **12***b* is placed between the central axis **59** and the second main electrode **11***b*.

The first sub electrode **12***a* of the plurality of second electrodes **12** is provided on the first main electrode **11***a* side on the first major surface **10***a* and extends in the Y-axis direction. The second sub electrode **12***b* of the plurality of second electrodes **12** is provided on the second main electrode **11***b* side on the first major surface **10***a* and extends in the Y-axis direction.

The second substrate unit **20***u* includes a second substrate **20** and an opposite electrode **21**. The second substrate **20** has a second major surface **20***a* opposed to the first major surface **10***a*. The plurality of first electrodes **11** and the plurality of second electrodes **12** are each provided between the first substrate **10** and the second substrate **20**.

The opposite electrode **21** is provided between the first substrate unit **10***u* and the second substrate **20**. In other words, the opposite electrode **21** is provided on the second major surface **20***a*. The opposite electrode **21** is opposed to each of the plurality of first electrodes **11** and the plurality of second electrodes **12**.

The first substrate **10**, the first electrode **11**, the second electrode **12**, the second substrate **20**, and the opposite electrode **21** are transmissive to light. Specifically, they are transparent.

The first substrate **10** and the second substrate **20** are made of e.g. a transparent material such as glass or resin. The first substrate **10** and the second substrate **20** are shaped like a plate or sheet. The thickness of the first substrate **10** and the second substrate **20** is e.g. 50 micrometers (μm) or more and 2000 μm or less. However, the thickness is arbitrary.

The first electrode **11**, the second electrode **12**, and the opposite electrode **21** include e.g. an oxide including at least one (kind of) element selected from the group consisting of In, Sn, Zn, and Ti. These electrodes are made of e.g. ITO. These electrodes may be made of e.g. at least one of In_2O_3 and SnO_3. The thickness of these electrodes is e.g. approximately 200 nanometers (nm) (e.g., 100 nm or more and 350 nm or less). The thickness of each electrode is set to e.g. a thickness such as to achieve high transmissivity to visible light.

The arrangement pitch of the first electrodes **11** (the distance between the centers in the X-axis direction of the two nearest first electrodes **11**) is e.g. 50 μm or more and 1000 μm or less. The arrangement pitch is set in conformity with the desired specification (the characteristics of the gradient index lens described later). The length (width) along the X-axis direction of the first electrode **11** and the second electrode **12** is e.g. 5 μm or more and 300 μm or less.

The liquid crystal layer **30** is provided between the first substrate unit **10**u and the second substrate unit **20**u. The liquid crystal layer **30** is provided between the plurality of first electrodes **11** and the opposite electrode **21** and between the plurality of second electrodes **12** and the opposite electrode **21**. The liquid crystal layer **30** includes a liquid crystal material. The liquid crystal material is a nematic liquid crystal (in a nematic phase at the operating temperature of the liquid crystal optical element **111**). The liquid crystal material has positive dielectric anisotropy or negative dielectric anisotropy. In the case of positive dielectric anisotropy, the initial arrangement of the liquid crystal in the liquid crystal layer **30** (the arrangement under no voltage application to the liquid crystal layer **30**) is e.g. horizontally oriented. In the case of negative dielectric anisotropy, the initial arrangement of the liquid crystal in the liquid crystal layer **30** is e.g. vertically oriented.

The length (thickness) of the liquid crystal layer **30** along the Z-axis direction is e.g. 10 μm or more and 50 μm or less. In this example, the thickness of the liquid crystal layer **30** is 40 μm. That is, the thickness of the liquid crystal layer **30** is the distance along the Z-axis direction between the first substrate unit **10**u and the second substrate unit **20**u.

The orientation of the liquid crystal in the liquid crystal layer **30** may have a pretilt. In the pretilt, for instance, the director **30**d of the liquid crystal is directed from the first substrate unit **10**u to the second substrate unit **20**u with the distance in the +X-direction from the first main electrode **11**a to the second main electrode **11**b.

The pretilt angle is the angle between the director **30**d (the axis in the long axis direction of the liquid crystal molecule) of the liquid crystal and the X-Y plane. In the case of horizontal orientation, the pretilt angle is e.g. more than 0° and less than 45°. In the case of vertical orientation, the pretilt angle is e.g. more than 45° and less than 90°.

In this specification, for convenience, the case of the pretilt angle less than 45° is referred to as horizontal orientation. The case of the pretilt angle more than 45° is referred to as vertical orientation.

The direction of pretilt can be determined by e.g. crystal rotation technique. The direction of pretilt can be determined also by observing the optical characteristics of the liquid crystal layer **30** when the orientation of the liquid crystal is changed by applying voltage to the liquid crystal layer **30**.

The first substrate unit **10**u may be subjected to orientation treatment such as rubbing. In this case, the direction of orientation treatment is directed along the +X-direction. In this example, the direction of orientation treatment in the first substrate unit **10**u is e.g. the +X-direction.

When the director **30**d of the liquid crystal is projected on the X-Y plane, the axis of the director **30**d may be parallel or non-parallel to the +X-direction. When the direction of pretilt is projected on the X-axis, the direction of pretilt includes a +X-direction component.

The orientation direction of the liquid crystal layer **30** near the second substrate unit **20**u is antiparallel to the orientation direction of the liquid crystal layer **30** near the first substrate unit **10**u. In this example, the direction of orientation treatment in the second substrate unit **20**u is the −X-direction. That is, the initial orientation is not the spray arrangement.

The first substrate unit **10**u further includes a first orientation film **41**. The first orientation film **41** is provided between the first substrate **10** and the liquid crystal layer **30**. The plurality of first electrodes **11** and the plurality of second electrodes **12** are provided between the first orientation film **41** and the first substrate **10**. The second substrate unit **20**u further includes a second orientation film **42**. The second orientation film **42** is provided between the second substrate **20** and the liquid crystal layer **30**. The opposite electrode **21** is provided between the second orientation film **42** and the second substrate **20**. The first orientation film **41** and the second orientation film **42** are made of e.g. polyimide. The initial arrangement of the liquid crystal layer **30** is obtained by performing e.g. rubbing treatment on the first orientation film **41** and the second orientation film **42**. The direction of rubbing treatment on the first orientation film **41** is antiparallel to the direction of rubbing treatment on the second orientation film **42**. The initial arrangement may be obtained by performing light irradiation treatment on the first orientation film **41** and the second orientation film **42**.

The thickness of the first orientation film **41** and the second orientation film **42** is e.g. 100 nm (e.g., 30 nm or more and 300 nm or less). The distance in the Z-axis direction between each of the plurality of first electrodes **11** and the liquid crystal layer **30** is e.g. 30 nm or more and 300 nm or less. The distance in the Z-axis direction between each of the plurality of second electrodes **12** and the liquid crystal layer **30** is e.g. 30 nm or more and 300 nm or less.

The following description is described with reference to the case where the liquid crystal included in the liquid crystal layer **30** has positive dielectric anisotropy and the initial arrangement is horizontally oriented.

A voltage is applied between the first electrode **11** and the opposite electrode **21** and between the second electrode **12** and the opposite electrode **21**. Thus, an electric field acts on the liquid crystal molecules in the liquid crystal layer **30** and changes the liquid crystal orientation. In response to this change, a refractive index distribution is formed in the liquid crystal layer **30**. This refractive index distribution changes the traveling direction of light incident on the liquid crystal optical element **111**. This change of the traveling direction of light is primarily based on the refraction effect.

The image display unit **80** includes a display unit **82** and a light source unit **84**. The display unit **82** and the light source unit **84** are stacked with the liquid crystal optical element **111**. The display unit **82** and the light source unit **84** are stacked with the liquid crystal lens device **211** (liquid crystal optical element **111**) in a third direction crossing the first direction and the second direction. The third direction is e.g. the Z-axis direction. The third direction is not limited to the Z-axis direction, but may be an arbitrary direction crossing the first direction and the second direction. In this example, the display unit **82** is provided between the liquid crystal optical element **111** and the light source unit **84**. The light source unit **84** emits light toward the display unit **82**. The display unit **82** transmits the incident light and outputs light including image information. That is, in this example, the display unit **82** is a display device of the transmission type. The light source unit **84** is what is called a back light. The display unit **82** injects the light including image information into the liquid crystal optical element **111**. The light source unit **84** can be omitted in the case where the display unit **82** is e.g. a display device of the self-emission type such as an organic EL display device.

The image display unit **80** can further include a display controller **86** for controlling the display unit **82**. The display unit **82** generates modulated light based on the signal supplied from the display controller **86**. The display unit **82** outputs e.g. light including a plurality of parallax images.

The driver **70** may be connected to the display controller **86** by a wired or wireless method (such as an electrical method or optical method). The image display device **311** may further include a controller (not shown) for controlling the driver **70** and the display controller **86**.

The display unit **82** has a display surface **82***a*. The display unit **82** outputs light including image information from the display surface **82***a*. The display surface **82***a* is shaped like e.g. a rectangle. The liquid crystal optical element **111** is provided on the display surface **82***a*. The length in the Y-axis direction of the first electrode **11** is slightly longer than the length in the Y-axis direction of the display surface **82***a*. The first electrode **11** traverses the display surface **82***a* in the Y-axis direction.

The display unit **82** includes a plurality of pixels PX arranged in a two-dimensional matrix. The plurality of pixels PX are arranged in the X-axis direction and the Y-axis direction. The display surface **82***a* is formed from the plurality of pixels PX.

The region between the two nearest first electrodes **11** is opposed to a plurality of pixels PX arranged in the X-axis direction. In the Z-axis direction, the region between the two nearest first electrodes **11** overlaps a plurality of pixels PX arranged in the X-axis direction. In this example, the region between the two nearest first electrodes **11** is opposed to three pixels PX arranged in the X-axis direction. That is, the spacing of the plurality of first electrodes **11** is wider than the spacing in the X-axis direction of the plurality of pixels PX. The number of the plurality of pixels PX opposed to the region between the two nearest first electrodes **11** and arranged in the X-axis direction is not limited to three, but may be two, or four or more.

The display unit **82** outputs e.g. light including an image to be displayed on the display surface **82***a*. This light is linearly polarized light traveling substantially in the Z-axis direction. The polarization axis (azimuth axis of the electric field oscillation plane in the X-Y plane) of this linearly polarized light is in the X-axis direction. That is, the polarization axis of this linearly polarized light is directed parallel to the director (long axis) of the liquid crystal molecule. This linearly polarized light is formed by e.g. placing an optical filter (polarizer) on the optical path. The polarization axis of the optical filter is in the X-axis direction.

The driver **70** is electrically connected to each of the plurality of first electrodes **11**, the plurality of second electrodes **12**, and the opposite electrode **21**. For clarity of illustration, FIG. **1** omits the illustration of part of the wiring between the driver **70** and the first electrode **11** and the illustration of the wiring between the driver **70** and the second electrode **12**.

Each of the plurality of liquid crystal molecules included in the liquid crystal layer **30** is horizontally oriented when no voltage is applied between the plurality of first electrodes **11** and the opposite electrode **21** and between the plurality of second electrodes **12** and the opposite electrode **21**. Thus, a nearly uniform refractive index distribution is exhibited in the X-axis direction and the Y-axis direction. Accordingly, the traveling direction of light including the image displayed in the display unit **82** is not substantially changed when no voltage is applied. That is, the liquid crystal optical element **111** is in the first state when no voltage is applied.

The driver **70** sets a potential to each of the plurality of first electrodes **11**, the plurality of second electrodes **12**, and the opposite electrode **21** when switching the liquid crystal optical element **111** from the first state to the second state. The driver **70** sets the absolute value of the potential difference between each of the plurality of first electrodes **11** and the opposite electrode **21** to V**1**. In other words, V**1** is the absolute value of the voltage between each of the plurality of first electrodes **11** and the opposite electrode **21**. In the following, for convenience, the aforementioned absolute value of the voltage is referred to as first voltage V**1**. The driver **70** applies the first voltage V**1** between each of the plurality of first electrodes **11** and the opposite electrode **21**.

The driver **70** sets the absolute value of the potential difference between each of the plurality of second electrodes **12** and the opposite electrode **21** to V**2**. In other words, V**2** is the absolute value of the voltage between each of the plurality of second electrodes **12** and the opposite electrode **21**. In the following, for convenience, the aforementioned absolute value of the voltage is referred to as second voltage V**2**. The driver **70** applies the second voltage V**2** between each of the plurality of second electrodes **12** and the opposite electrode **21**.

The first voltage V**1** is higher than the second voltage V**2**. Thus, when the first voltage V**1** and the second voltage V**2** are applied, the tilt angle of the liquid crystal molecules is larger in the first portion **30***a* of the liquid crystal layer **30** in which the first electrode **11** is opposed to the opposite electrode **21**. In the first portion **30***a*, for instance, the orientation of the liquid crystal molecules is close to vertical orientation. On the other hand, the liquid crystal molecules remain horizontally oriented in the second portion **30***b* of the liquid crystal layer **30** around the center of the two adjacent first electrodes **11**. In the portion between the first portion **30***a* and the second portion **30***b*, the angle (tilt angle) of the liquid crystal molecules gradually changes toward vertical orientation from the second portion **30***b* toward the first portion **30***a*. The liquid crystal molecules change the angle of the long axis in the Z-X plane. The angle of the long axis of the liquid crystal molecules changes about the Y-axis direction.

The liquid crystal molecule has birefringence. The refractive index in the long axis direction of the liquid crystal molecule to polarized light is higher than the refractive index in the short axis direction of the liquid crystal molecule. The angle of the liquid crystal molecules is changed as described above. Consider the case where linearly polarized light travels in the Z-axis direction, and the polarization axis of the linearly polarized light is directed in the X-axis direction. The refractive index of the liquid crystal layer **30** with respect to this linearly polarized light is high in the second portion **30***b* of the liquid crystal layer **30**, and gradually decreases toward the first portion **30***a*. Thus, a refractive index distribution shaped like a convex lens (semicircle) is formed.

The plurality of first electrodes **11** extend along the Y-axis direction. Thus, the refractive index distribution of the liquid crystal layer **30** under voltage application is shaped like a cylindrical lens extending along the Y-axis direction. The plurality of first electrodes **11** are arranged in the X-axis direction. Thus, as viewed over the entire liquid crystal layer **30**, the refractive index distribution of the liquid crystal layer **30** under voltage application is shaped like a lenticular lens in which a plurality of cylindrical lenses extending along the Y-axis direction are arranged in the X-axis direction.

The polarity of the first voltage V**1** and the second voltage V**2** may be e.g. periodically changed. For instance, the potential of the opposite electrode **21** may be fixed, and the potential of the first electrode **11** or the potential of the second electrode **12** may be changed in AC mode. Alternatively, the polarity of the potential of the opposite electrode **21** may be periodically changed. In conjunction with this change of polarity, the potential of the first electrode **11** or the potential of the second electrode **12** may be changed in the opposite polarity. That is, common inversion driving may be performed. This can decrease the power supply voltage of the driving circuit. Thus, the breakdown voltage specification of the driving IC is relaxed.

The refractive index distribution formed in the liquid crystal layer **30** and shaped like a convex lens is opposed to a plurality of pixels PX arranged in the X-axis direction of the display unit **82**. In this example, the portion (second portion **30***b*) having higher refractive index in the refractive index distribution of the liquid crystal layer **30** is opposed to the central pixel PX of the three pixels PX arranged in the X-axis direction.

The refractive index distribution of the liquid crystal layer **30** under voltage application causes light (image) outputted from each pixel PX to travel toward the observer's eye. Thus, the image formed by each of the three pixels PX opposed to the refractive index distribution constitutes a parallax image. That is, in this example, the three pixels PX arranged in the X-axis direction form three parallax images. The parallax image for the right eye is selectively incident on the observer's right eye. The parallax image for the left eye is selectively incident on the observer's left eye. This enables 3D display. That is, the liquid crystal optical element **111** is in the second state when a voltage is applied to each of the plurality of first electrodes **11**, the plurality of second electrodes **12**, and the opposite electrode **21**.

When the liquid crystal optical element **111** is in the first state, the light outputted from each pixel PX travels in a straight line and is incident on the observer's eye. This enables 2D display. In 2D display, an ordinary 2D image can be displayed at a resolution multiplied by the number of parallax (in this example, three) relative to 3D display.

The plurality of pixels PX can be provided with color filters each including three RGB primary colors. This enables color display. The color filter may further include white (colorless) or other color elements besides the three RGB primary colors.

Thus, in the liquid crystal optical element **111** of the image display device **311**, the refractive index distribution of the liquid crystal layer **30** is changed by applying or not applying voltage to the plurality of first electrodes **11**, the plurality of second electrodes **12**, and the opposite electrode **21**. Accordingly, 2D display and 3D display are switched.

The distance between the first main electrode **11***a* and the first sub electrode **12***a* is denoted by Pa. The distance between the second main electrode **11***b* and the second sub electrode **12***b* is denoted by Pb. More specifically, the distance Pa is the distance in the X-axis direction between the center **11***ac* in the X-axis direction of the first main electrode **11***a* and the center **12***ac* in the X-axis direction of the first sub electrode **12***a*. The distance Pb is the distance in the X-axis direction between the center **11***bc* in the X-axis direction of the second main electrode **11***b* and the center **12***bc* in the X-axis direction of the second sub electrode **12***b*. The distance Pb is substantially equal to the distance Pa.

The distance in the Z-axis direction between the first electrode **11** and the opposite electrode **21** is denoted by d**1**. The distance in the Z-axis direction between the second electrode **12** and the opposite electrode **21** is denoted by d**2**. The distance d**1** is substantially equal to the distance d**2**. That is, the thickness of the first electrode **11** is substantially equal to the thickness of the second electrode **12**. In other words, the distance d**1** and the distance d**2** are the thickness of the liquid crystal layer **30** between the respective electrodes.

The distance Pa and the distance Pb are longer than the distance d**1** and the distance d**2**. That is, the distance between the first electrode **11** and the second electrode **12** is longer than the thickness of the liquid crystal layer **30**.

The distance between the first main electrode **11***a* and the second main electrode **11***b* is denoted by P**1**. The distance between the first sub electrode **12***a* and the second sub electrode **12***b* is denoted by P**2**. More specifically, the distance P**1** is the distance in the X-axis direction between the center **11***ac* in the X-axis direction of the first main electrode **11***a* and the center **11***bc* in the X-axis direction of the second main electrode **11***b*. The distance P**2** is the distance in the X-axis direction between the center **12***ac* in the X-axis direction of the first sub electrode **12***a* and the center **12***bc* in the X-axis direction of the second sub electrode **12***b*.

In the liquid crystal optical element **111**, the distance P**1**, the distance P**2**, the first voltage V**1**, and the second voltage V**2** described above satisfy the relation of the following formula (1).

$$V2/V1 \leq P2/P1 \tag{1}$$

That is, the ratio V**2**/V**1** of the second voltage V**2** to the first voltage V**1** is less than or equal to the ratio P**2**/P**1** of the distance P**2** between the second electrodes **12** to the distance P**1** between the first electrodes **11**.

In the liquid crystal optical element **111**, the distance P**1** and the distance P**2** are set so as to satisfy the relation of formula (1). The driver **70** sets the first voltage V**1** and the second voltage V**2** so as to satisfy the relation of formula (1). That is, the driver **70** sets the potential of each of the plurality of first electrodes **11**, the plurality of second electrodes **12**, and the opposite electrode **21** so as to satisfy the relation of formula (1). In formula (1), the distances P**1**, P**2** are expressed in units of μm (micrometers). The first voltage V**1** and the second voltage V**2** are expressed in units of V (volts).

The distance P**2** is e.g. half or less of the distance P**1**, The distance P**1** is e.g. 260 μm (20 μm or more and 1000 μm or less). The distance P**2** is e.g. 130 μm (10 μm or more and 500 μm or less). The distance d**1** and the distance d**2** (the thickness of the liquid crystal layer **30**) are e.g. 40 μm (20 μm or more and 50 μm or less). The first voltage V**1** is e.g. 5 V (3 V or more and 7 V or less). The second voltage V**2** is e.g. 1.2 V (0.5 V or more and 2.5 V or less).

The first voltage V**1** applied to the first electrode **11** is higher than the second voltage V**2** applied to the second electrode **12**. In the liquid crystal layer **30**, an effect of strong electric field occurs near the distance D**1** (distance comparable to the thickness of the liquid crystal layer **30**) in the X-axis direction away from the first electrode **11**. If the second electrode **12** is placed in the region in which this strong electric field occurs, the electric field induced by the first electrode **11** strongly interacts with the electric field induced by the second electrode **12**. This is likely to disturb the liquid crystal orientation.

Thus, the distance Pa and the distance Pb are made longer than the distance d**1** and the distance d**2**. This can suppress the disturbance of liquid crystal orientation.

FIG. **2** is a graph schematically showing an example of the characteristics of the liquid crystal lens device according to the first embodiment.

FIG. **2** schematically shows an example of the experimental results. In the experiment, a plurality of samples with different P**2**/P**1** were prepared. For each sample, the focusing ratio FR was measured with V**2**/V**1** changed. The focusing ratio FR refers to the ratio of light focused at an arbitrary focal distance for a light beam incident on one unit of the refractive index distribution shaped like a convex lens of the liquid crystal layer **30**. In the case of low focusing ratio FR, only part of the light incident on the refractive index distribution shaped like a convex lens focuses at the focal distance. The rest becomes scattered light or stray light. For instance, the focusing ratio FR can be determined as the ratio between the light intensity of the entire lens incidence surface and the light intensity of the entire focusing surface having an arbitrary area. The light intensity is measured by a luminance meter. The horizontal axis of FIG. **2** represents the ratio (V**2**/V**1**)/(P**2**/P**1**) of the voltage V**1**, V**2** and the distance P**1**, P**2** set to each sample in the experiment. The vertical axis of FIG. **2** represents the measured focusing ratio FR.

The focusing ratio FR is set to 0.8 or more. This can suppress e.g. scattering of light. Thus, the refractive index distribution of the liquid crystal layer **30** can be appropriately caused to function as a lens. For instance, in 3D display, this can suppress e.g. crosstalk of parallax images and achieve high display quality.

As shown in FIG. **2**, if (V**2**/V**1**)/(P**2**/P**1**) is more than 1, there are more conditions of voltage and electrode position with the focusing ratio FR less than 0.8. Thus, in the case where (V**2**/V**1**)/(P**2**/P**1**) is more than 1, the lens performance is prone to degradation in response to the variation of voltage and electrode position due to e.g. manufacturing accuracy.

On the other hand, in the case where (V**2**/V**1**)/(P**2**/P**1**) is 1 or less, the degradation of lens performance can be suppressed even under slight variation of the condition of voltage and electrode position. Furthermore, this can easily achieve high lens performance such that the focusing ratio FR exceeds 0.9. For instance, (V**2**/V**1**)/(P**2**/P**1**) is set to 0.5 or more and 1 or less. This can achieve good lens performance in the refractive index distribution of the liquid crystal layer **30**.

For instance, the distance Pa, Pb is short. The second electrode **12** is placed near the first electrode **11**. The application voltage of the second electrode **12** is low. In this case, the horizontally oriented region around the lens center is widened. This causes concern that the lens characteristic is flattened at the center.

For instance, the distance Pa, Pb is short. The second electrode **12** is placed near the first electrode **11**. The application voltage of the second electrode **12** is high. In this case, the region close to vertical orientation near the lens edge is widened. This causes concern that the lens characteristic is shaped like a prism.

For instance, the second electrode **12** is placed near the center. The application voltage of the second electrode **12** is high. In this case, there is concern that the lens characteristic is distorted in the portion between the second electrode **12** and the opposite electrode **21**.

In the liquid crystal lens device **211** and the image display device **311** according to this embodiment, the distance Pa and the distance Pb are made longer than the distance d**1** and the distance d**2**. The placement and application voltage of each electrode are set so as to satisfy the relation of V**2**/V**1** P**2**/P**1**. Thus, for instance, good refractive index distribution shaped like a convex lens can be formed in the liquid crystal layer **30**. For instance, this can suppress the decrease of focusing ratio FR. Furthermore, a high quality lens function can be provided. For instance, high quality 3D display can be provided.

In the liquid crystal lens device **211** and the image display device **311**, the electrodes placed between the two nearest first electrodes **11** are only two electrodes, i.e., the first sub electrode **12***a* and the second sub electrode **12***b*. This can improve manufacturability relative to the case where more electrodes are formed between the two nearest first electrodes **11**. Furthermore, the number of applied voltages can be reduced to two, i.e., the first voltage V**1** and the second voltage V**2**. This can simplify e.g. the configuration of the driver **70**.

The number of second electrodes **12** placed between the two nearest first electrodes **11** is not limited to two, but may be three or more. Electrodes other than the second electrodes **12** may be further provided between the two nearest first electrodes **11**.

FIGS. **3**A and **3**B are sectional views schematically showing part of an alternative image display device according to the first embodiment.

FIGS. **3**A and **3**B show only the liquid crystal optical element **112**, **113** for convenience. The driver **70** and the image display unit **80** can be configured similarly to the above embodiment. In the following, the components substantially the same in function or configuration as those of the above embodiment are labeled with like reference numerals, and the detailed description thereof is omitted.

As shown in FIG. **3**A, in the liquid crystal optical element **112**, the distance P**2** in the X-axis direction between the first sub electrode **12***a* and the second sub electrode **12***b* is less than or equal to the distance Pa in the X-axis direction between the first main electrode **11***a* and the first sub electrode **12***a*, and the distance Pb in the X-axis direction between the second main electrode **11***b* and the second sub electrode **12***b*.

In the liquid crystal optical element **112**, the distance P**2** is e.g. 70 μm. The distance Pa and the distance Pb are e.g. 120 μm. The first voltage V**1** is e.g. three times or more the second voltage V**2**. The first voltage V**1** is e.g. 5 V. The second voltage V**2** is e.g. 1 V.

Thus, the second electrode **12** is made close to the central axis **59**. Accordingly, the electric field induced by the second electrode **12** is applied more easily to the region in which the electric field effect of the first electrode **11** is weaker. Thus, the refractive index distribution shaped like a convex lens is formed more easily. For instance, this can further improve the focusing performance of the refractive index distribution shaped like a convex lens.

The distance P**2** in the X-axis direction between the first sub electrode **12***a* and the second sub electrode **12***b* is set to half or more of the distance d**1** and the distance d**2**. That is, the distance P**2** is set to half or more of the thickness of the liquid crystal layer **30**. This can suppress the occurrence of disclination caused by the interaction of electric field between the first sub electrode **12***a* and the second sub electrode **12***b*. For instance, the display quality of 3D display can be further enhanced.

As shown in FIG. **3**B, in the liquid crystal optical element **113**, the distance P**2** in the X-axis direction between the first sub electrode **12***a* and the second sub electrode **12***b* is a quarter or less of the distance P**1** in the X-axis direction between the first main electrode **11***a* and the second main electrode **11***b*.

In the liquid crystal optical element **113**, the distance P**2** is e.g. 60 μm. The distance P**1** is e.g. 300 μm. The first voltage V**1** is e.g. three times or more the second voltage V**2**. The first voltage V**1** is e.g. 5 V. The second voltage V**2** is e.g. 1 V. The distance P**2** is half or more of the distance d**1** and the distance d**2**.

Thus, the second electrode **12** is made further close to the central axis **59**. Accordingly, the electric field induced by the second electrode **12** is applied still more easily to the region in which the electric field effect of the first electrode **11** is weaker. Thus, the refractive index distribution shaped like a convex lens is formed more easily. For instance, this can further improve the focusing performance of the refractive index distribution shaped like a convex lens.

Second Embodiment

FIG. **4** is a sectional view schematically showing an image display device according to a second embodiment.

As shown in FIG. **4**, in the image display device **321** and the liquid crystal lens device **221**, the first substrate unit **10***u* of the liquid crystal optical element **121** further includes a central electrode **13**. The central electrode **13** is provided on the first major surface **10***a*. As projected on the plane (X-Y plane) parallel to the X-axis direction and the Y-axis direction, the central electrode **13** overlaps the central axis **59**. In other words, the central electrode **13** is placed on the central axis **59** between the two nearest first electrodes **11**. The central electrode **13** is provided between the first sub electrode **12***a* and the second sub electrode **12***b*. The central electrode **13** is spaced from the first sub electrode **12***a* and the second sub electrode **12***b*. The central electrode **13** is light transmissive. The central electrode **13** is e.g. transparent. The central electrode **13** can be made of e.g. the material described with reference to the first electrode **11** and the second electrode **12**.

The central electrode **13** is electrically connected to the driver **70**. The driver **70** places the central electrode **13** at e.g. substantially the same potential as that of the opposite electrode **21**. That is, the driver **70** sets the voltage between the central electrode **13** and the opposite electrode **21** to substantially 0 V. The driver **70** applies a third voltage V3 between the central electrode **13** and the opposite electrode **21**. The third voltage V3 is substantially 0 V.

Thus, in the liquid crystal lens device **221** and the image display device **321**, the central electrode **13** is further provided on the first substrate unit **10***u*. This can improve e.g. the flexibility of adjusting the shape of refractive index distribution around the lens center. For instance, the lens performance (focusing ratio FR) can be further improved. The central electrode **13** is placed at substantially the same potential as the opposite electrode **21**. For instance, this eliminates the need of preparing a new voltage in the driver **70**. For instance, the complication of the driver **70** can be suppressed even in the case of providing the central electrode **13**. In the case of providing the central electrode **13**, the electrodes placed between the two nearest first electrodes **11** are only three electrodes, i.e., the first sub electrode **12***a*, the second sub electrode **12***b*, and the central electrode **13**. This can suppress the decrease of manufacturability of the liquid crystal lens device **221**.

Third Embodiment

FIG. **5** is a sectional view schematically showing an image display device according to a third embodiment.

As shown in FIG. **5**, in the image display device **331** and the liquid crystal lens device **231**, the liquid crystal optical element **131** is provided between the display unit **82** and the light source unit **84**. In the liquid crystal optical element **131**, the light emitted from the light source unit **84** and transmitted through the liquid crystal optical element **131** is incident on the display unit **82**.

Thus, the liquid crystal optical element **131** may be provided between the display unit **82** and the light source unit **84**. In this example, the liquid crystal optical element **131** is substantially the same as the liquid crystal optical element **111** described in the above first embodiment. The liquid crystal optical element **131** is not limited thereto, but may have any of the configurations described in the first embodiment and the second embodiment.

In the above embodiments, the display unit **82** is a display device of the transmission type. The display unit **82** is not limited thereto, but may be a display device of the reflection type. In the case of using a display device of the reflection type for the display unit **82**, the light source unit **84** may be omitted. In the case of using a display device of the reflection type for the display unit **82**, for instance, a light source unit **84** of the front light type may be used. For instance, the liquid crystal optical element **131** may be provided on the display surface **82***a* of the display unit **82**, and the light source unit **84** may be provided on the liquid crystal optical element **131**.

The embodiments can provide a liquid crystal lens device having a high quality lens function. This liquid crystal lens device can be used to provide an image display device providing high quality display.

In this specification, "perpendicular" and "parallel" mean not only being exactly perpendicular and exactly parallel, but include e.g. variations in the manufacturing process, and only need to mean being substantially perpendicular and substantially parallel. In this specification, the state of being "provided on" includes not only the state of being provided in direct contact, but also the state of being provided with another element interposed in between. The state of being "stacked" includes not only the state of being stacked in contact with each other, but also the state of being stacked with another element interposed in between. The state of being "opposed" includes not only the state of directly facing, but also facing with another element interposed in between.

Hereinabove, embodiments of the invention are described with reference to specific examples. However, the embodiments of the invention are not limited to these specific examples. For example, one skilled in the art may similarly practice the invention by appropriately selecting specific configurations of components included in liquid crystal lens devices and image display devices such as drivers, display units, image display units, first substrate units, second substrate units, liquid crystal layers, first substrates, second substrates, first electrodes, second electrodes, first sub electrodes, second sub electrodes, center electrodes, opposite electrodes, etc., from known art; and such practice is included in the scope of the invention to the extent that similar effects are obtained.

Further, any two or more components of the specific examples may be combined within the extent of technical feasibility and are included in the scope of the invention to the extent that the purport of the invention is included.

Moreover, all liquid crystal lens devices and image display devices practicable by an appropriate design modification by one skilled in the art based on the liquid crystal lens devices and image display devices described above as embodiments of the invention also are within the scope of the invention to the extent that the spirit of the invention is included.

Various other variations and modifications can be conceived by those skilled in the art within the spirit of the invention, and it is understood that such variations and modifications are also encompassed within the scope of the invention.

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and theft equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the invention.

What is claimed is:

1. A liquid crystal lens device comprising:

a plurality of first electrodes extending in a first direction and arranged in a second direction crossing the first direction;

a first sub electrode provided between a center in the second direction of two nearest ones of the first electrodes and one of the two nearest first electrodes;

a second sub electrode provided between the center and the other of the two nearest first electrodes;

an opposite electrode opposed to each of the first electrodes, the first sub electrode, and the second sub electrode; and

a liquid crystal layer provided between the first electrodes and the opposite electrode, between the first sub electrode and the opposite electrode, and between the second sub electrode and the opposite electrode,

a distance between the one of the two nearest first electrodes and the first sub electrode and a distance between the other of the two nearest first electrodes and the second sub electrode being longer than a distance between each of the first electrodes and the opposite electrode, and

V2/**V1** being less than or equal to **P2**/**P1**,

where **V1** is an absolute value of a potential difference between each of the first electrodes and the opposite electrode,

V2 is an absolute value of a potential difference between the first sub electrode and the opposite electrode and between the second sub electrode and the opposite electrode,

P1 is a distance between the two nearest first electrodes, and

P2 is a distance between the first sub electrode and the second sub electrode.

2. The device according to claim **1**, wherein electrodes provided between the two nearest first electrodes are only two electrodes that are the first sub electrode and the second sub electrode.

3. The device according to claim **1**, further comprising:

a central electrode provided at the center between the two nearest first electrodes.

4. The device according to claim **1**, wherein the **V1** is three times or more the **V2**.

5. The device according to claim **1**, wherein the distance between the first sub electrode and the second sub electrode is half or less of the distance between the two nearest first electrodes.

6. The device according to claim **1**, wherein the distance between the first sub electrode and the second sub electrode is less than or equal to the distance between the one of the two nearest first electrodes and the first sub electrode and the distance between the other of the two nearest first electrodes and the second sub electrode.

7. The device according to claim **1**, wherein the distance between the first sub electrode and the second sub electrode is a quarter or less of the distance between the two nearest first electrodes.

8. The device according to claim **1**, wherein the distance between the first sub electrode and the second sub electrode is half or more of the distance between each of the first electrodes and the opposite electrode.

9. The device according to claim **1**, wherein a distance between each of the first electrodes and the liquid crystal layer, a distance between the first sub electrode and the liquid crystal layer, and a distance between the second sub electrode and the liquid crystal layer are 30 am or more and 300 am or less.

10. The device according to claim **1**, further comprising:

a driver electrically connected to each of the first electrodes, the first sub electrode, the second sub electrode, and the opposite electrode and configured to set a potential to each of the first electrodes, the first sub electrode, the second sub electrode, and the opposite electrode, the potential being such that **V2**/**V1** is less than or equal to **P2**/**P1**.

11. The device according to claim **10**, wherein the driver changes a refractive index distribution formed in the liquid crystal layer by switching between a state of setting the potential and a state of not setting the potential.

12. The device according to claim **1**, further comprising:

a first substrate having a first major surface; and

a second substrate having a second major surface opposed to the first major surface,

the first electrodes, the first sub electrode, and the second sub electrode being provided on the first major surface,

the opposite electrode being provided on the second major surface, and

the liquid crystal layer is provided between the first substrate and the second substrate.

13. The device according to claim **1**, wherein the liquid crystal layer includes a liquid crystal material having a positive dielectric anisotropy.

14. The device according to claim **13**, wherein an initial arrangement of the liquid crystal material is a horizontally oriented.

15. The device according to claim **1**, wherein (**V2**/**V1**)/(**P2**/**P1**) is 0.5 or more and 1 or less.

16. The device according to claim **1**, wherein

the **P1** is 20 μm or more and 1000 μm or less,

the **P2** is 10 μm or more and 500 μm or less,

the **V1** is 3 V or more and 7 V or less, and

the **V2** is 0.5 V or more and 2.5 V or less.

17. An image display device comprising:

a liquid crystal lens device including:

a plurality of first electrodes extending in a first direction and arranged in a second direction crossing the first direction;

a first sub electrode provided between a center in the second direction of two nearest ones of the first electrodes and one of the two nearest first electrodes;

a second sub electrode provided between the center and the other of the two nearest first electrodes;

an opposite electrode opposed to each of the first electrodes, the first sub electrode, and the second sub electrode; and

a liquid crystal layer provided between the first electrodes and the opposite electrode, between the first sub electrode and the opposite electrode, and between the second sub electrode and the opposite electrode; and an image display unit stacked with the liquid crystal lens device in a third direction crossing the first direction and the second direction and including a display unit configured to output a light including image information,

a distance between the one of the two nearest first electrodes and the first sub electrode and a distance between the other of the two nearest first electrodes and the second sub electrode being longer than a distance between each of the first electrodes and the opposite electrode, and

V**2**/V**1** being less than or equal to P**2**/P**1**,

where V**1** is an absolute value of a potential difference between each of the first electrodes and the opposite electrode,

V**2** is an absolute value of a potential difference between the first sub electrode and the opposite electrode and between the second sub electrode and the opposite electrode,

P**1** is a distance between the two nearest first electrodes, and

P**2** is a distance between the first sub electrode and the second sub electrode.

18. The device according to claim **17**, wherein

the display unit includes a plurality of pixels arranged in the second direction, and

a region between the two nearest first electrodes overlaps the pixels in the third direction.

19. The device according to claim **17**, wherein

the image display unit further includes a light source unit configured to emit a light toward the display unit, and

the display unit is provided between the liquid crystal lens device and the light source unit.

20. The device according to claim **17**, wherein

the image display unit further includes a light source unit configured to emit a light toward the display unit, and

the liquid crystal lens device is provided between the display unit and the light source unit.

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